Jet Propulsion Laboratory
California Institute of Technology

Laboratory tests on Europa's surface simulants to infer the crustal material behavior down to the cm scale

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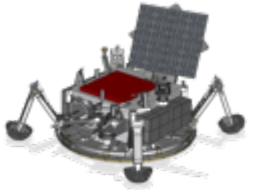
Jet Propulsion Laboratory, California Institute of Technology

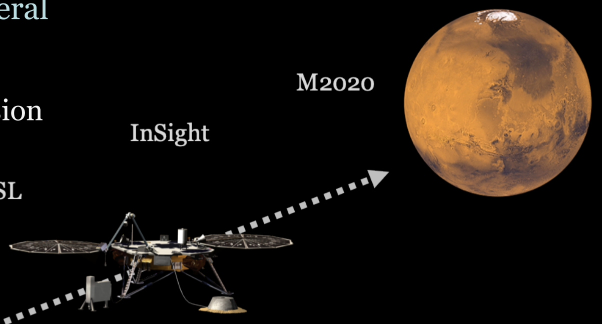
AGU Meeting, San Francisco, 12-10-2019

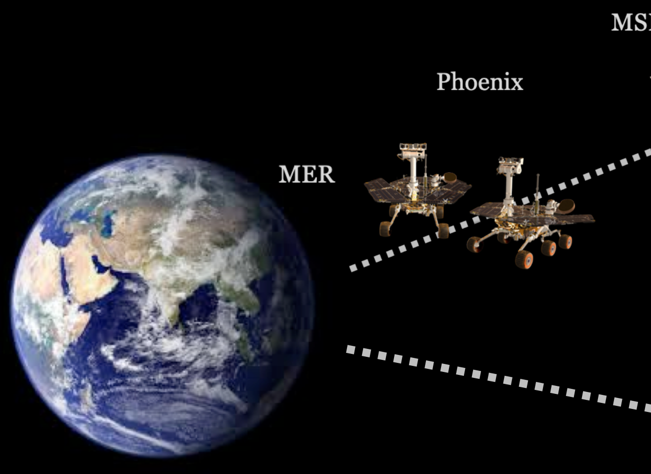
Mars Mission History



We have knowledge built over time and several missions

- Learned the framework for successful mission design





Our flight experience is mostly based on Mars, which is similar to Earth and well characterized

- Geo-analog simulants are easier to find or engineer
- Tool design is more intuitive

Icy Worlds, comets, and asteroids present novel problems for landing, mobility and sampling

- Vacuum
- Cryogenic temperatures
- Micro gravity

Earth analogs will need to be manufactured

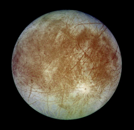
- The range of expected materials on these bodies is not well characterized
- Manufacturing cryogenic (70 K) ice simulants requires development and infrastructure

Technology investment and preparedness will be critical in successful flight missions

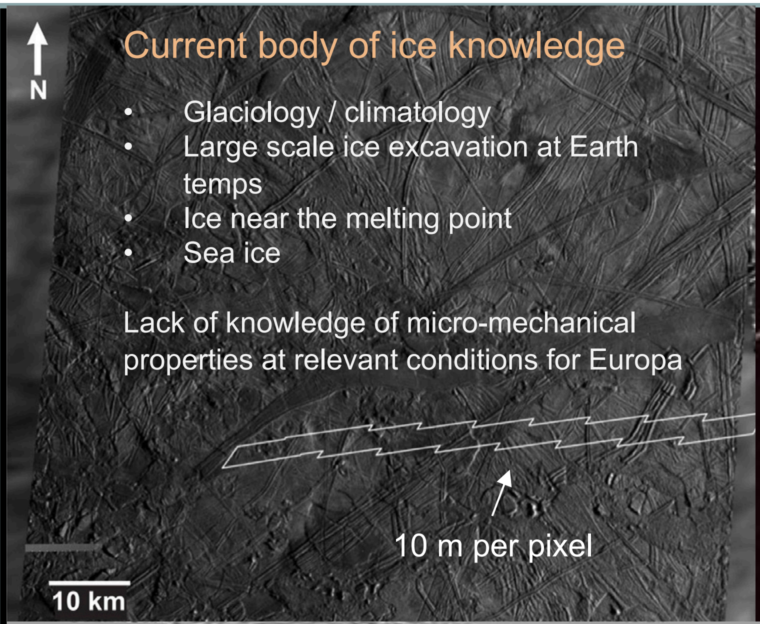
Now we want to condense these steps

- We aim to apply the mission-design concept to other extraterrestrial bodies, such as Europa, with the advantage of reducing time and number of missions to achieve successful sample collection and analysis.

Due to the cost and time to develop a mission landing on Europa, we cannot iterate over multiple missions as we did for Mars. Thus, it is paramount to minimize the uncertainties.



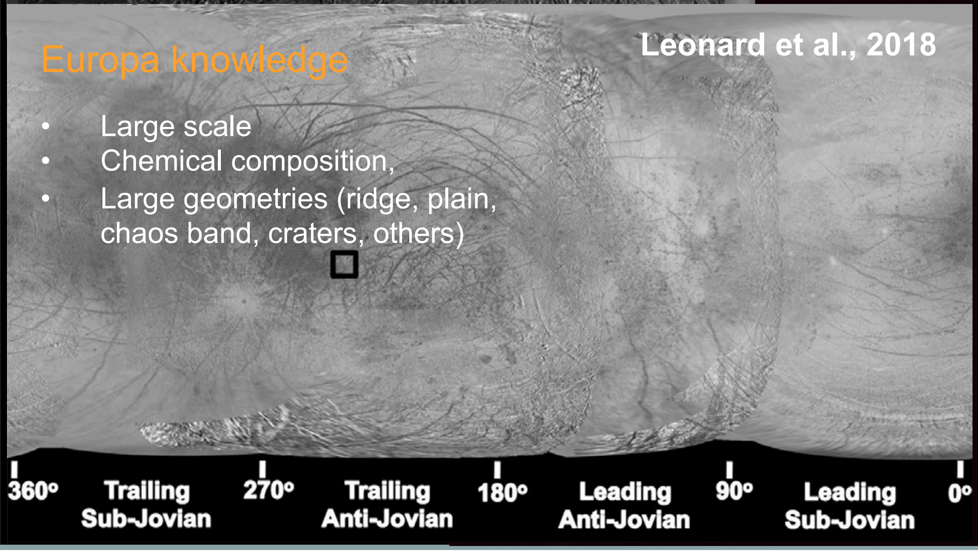
Lesson learned from Galileo mission



Current body of ice knowledge

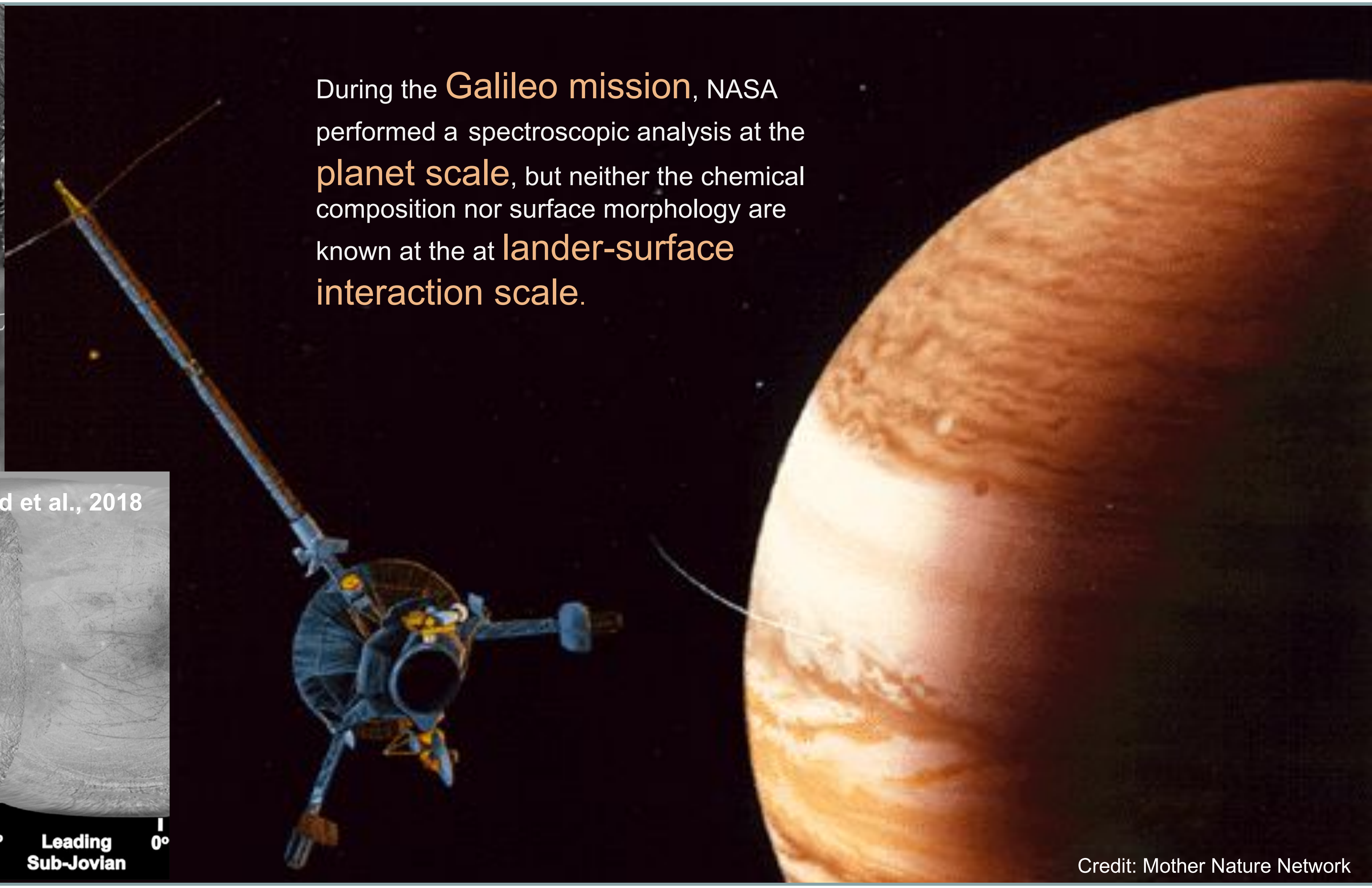
- Glaciology / climatology
- Large scale ice excavation at Earth temps
- Ice near the melting point
- Sea ice

Lack of knowledge of micro-mechanical properties at relevant conditions for Europa



Europa knowledge

- Large scale
- Chemical composition,
- Large geometries (ridge, plain, chaos band, craters, others)

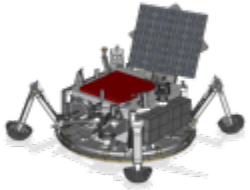


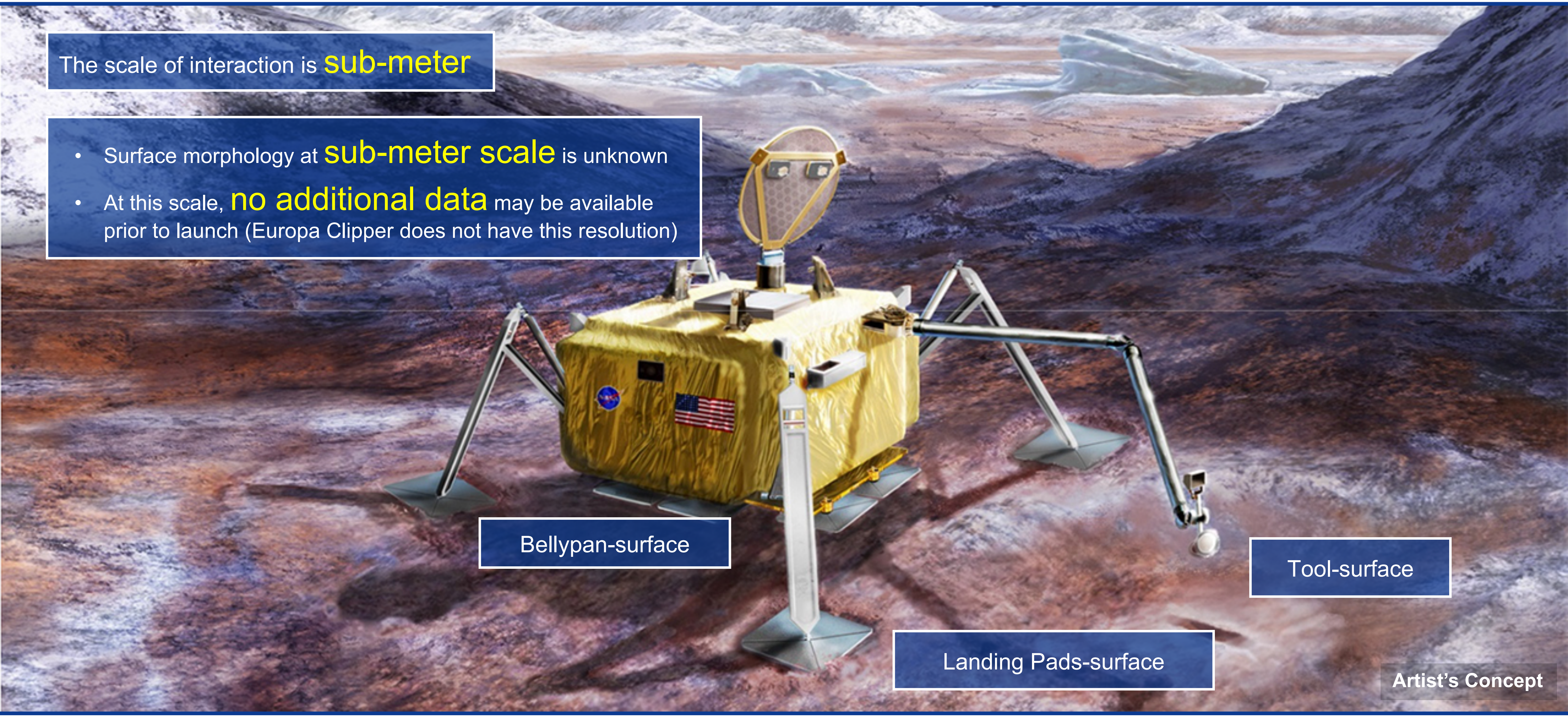
During the Galileo mission, NASA performed a spectroscopic analysis at the planet scale, but neither the chemical composition nor surface morphology are known at the at lander-surface interaction scale.

Credit: Mother Nature Network

Problem Statement

Lack of knowledge at the lander scale

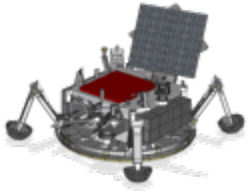




The scale of interaction is **sub-meter**

- Surface morphology at **sub-meter scale** is unknown
- At this scale, **no additional data** may be available prior to launch (Europa Clipper does not have this resolution)

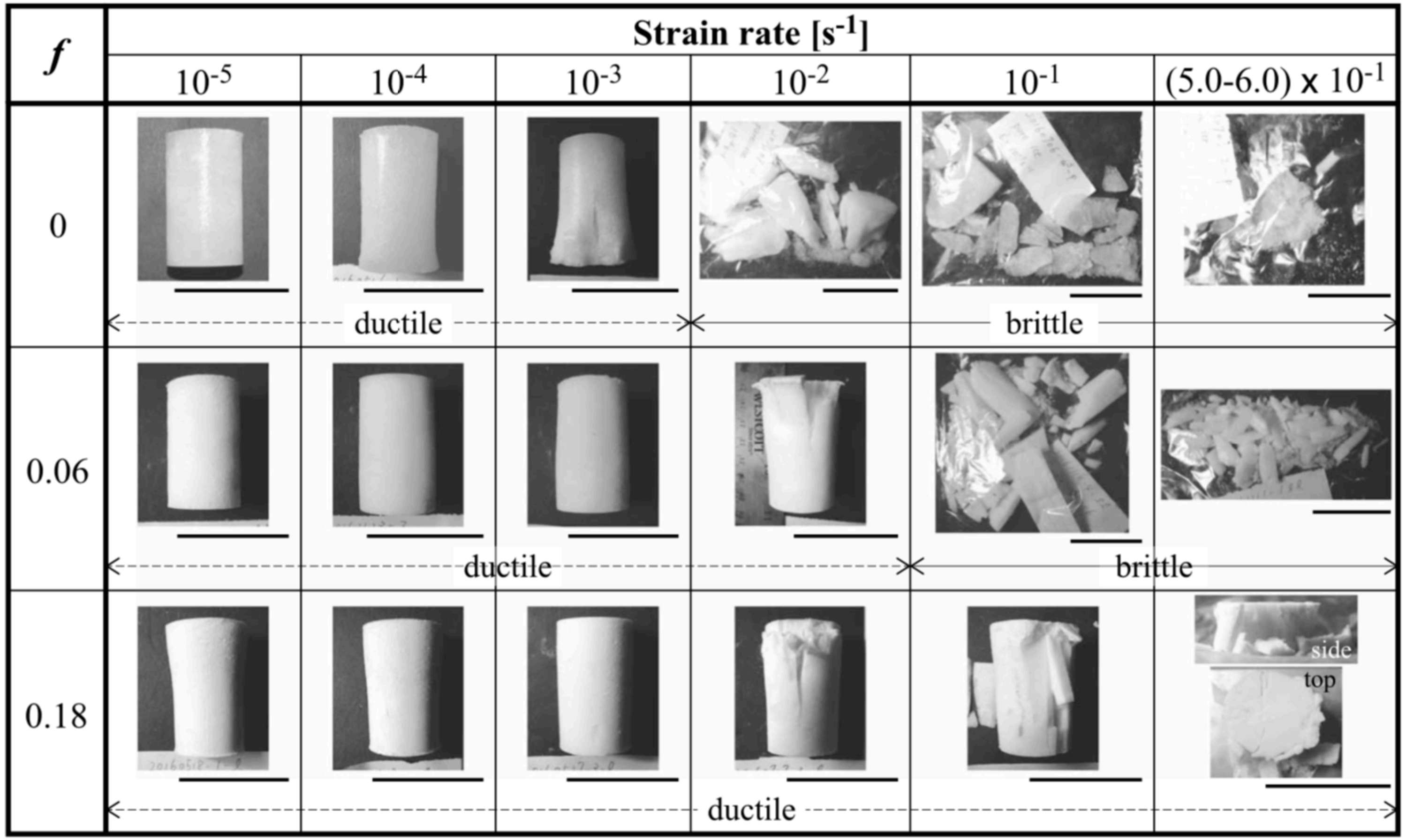
Viscoelastic behavior of ice



Compressive strength vs. strain rate

This is a 2-axis example, of a much broader parametric space

f : silica volume fraction



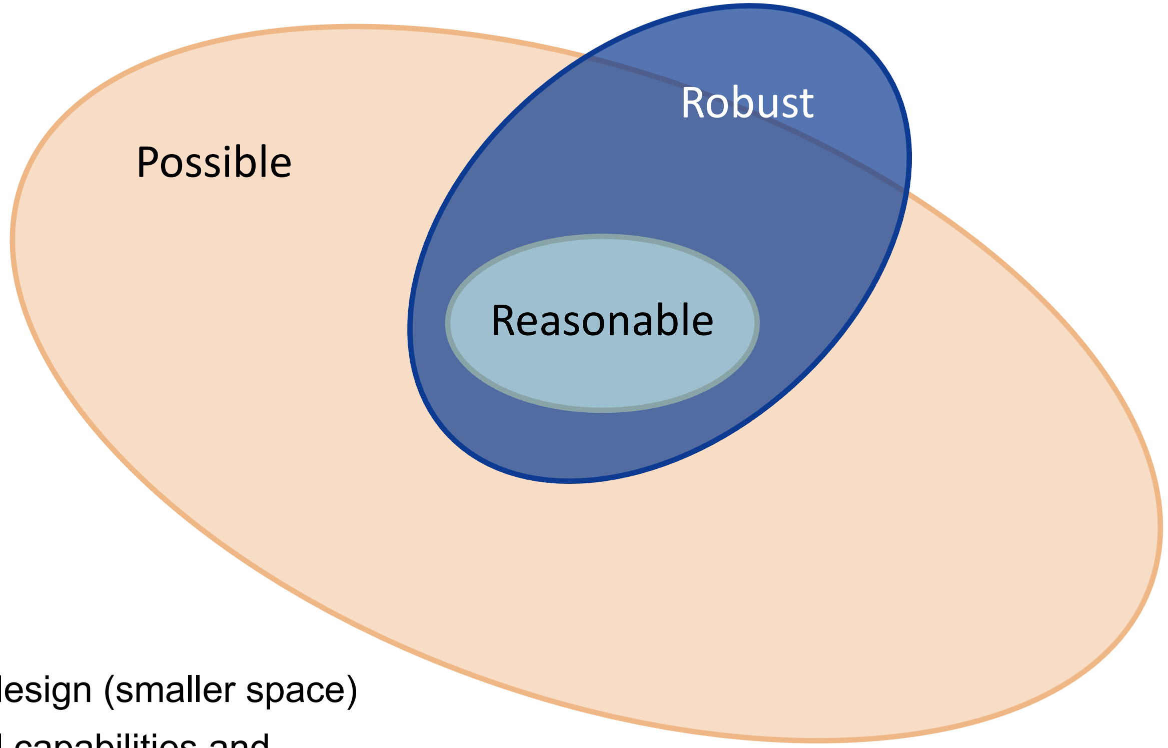
Yasui et al., 2017

- Ice behavior **strongly depends** on strain rate.
- Below a certain value of strain rate, ice manifests ductile behavior, while, above that value, it transitions to a brittle one.
- The transition varies depending on temperature, presence of chemicals, porosity (?), crystal structure (?).

How we plan on using this data

and how it adds value

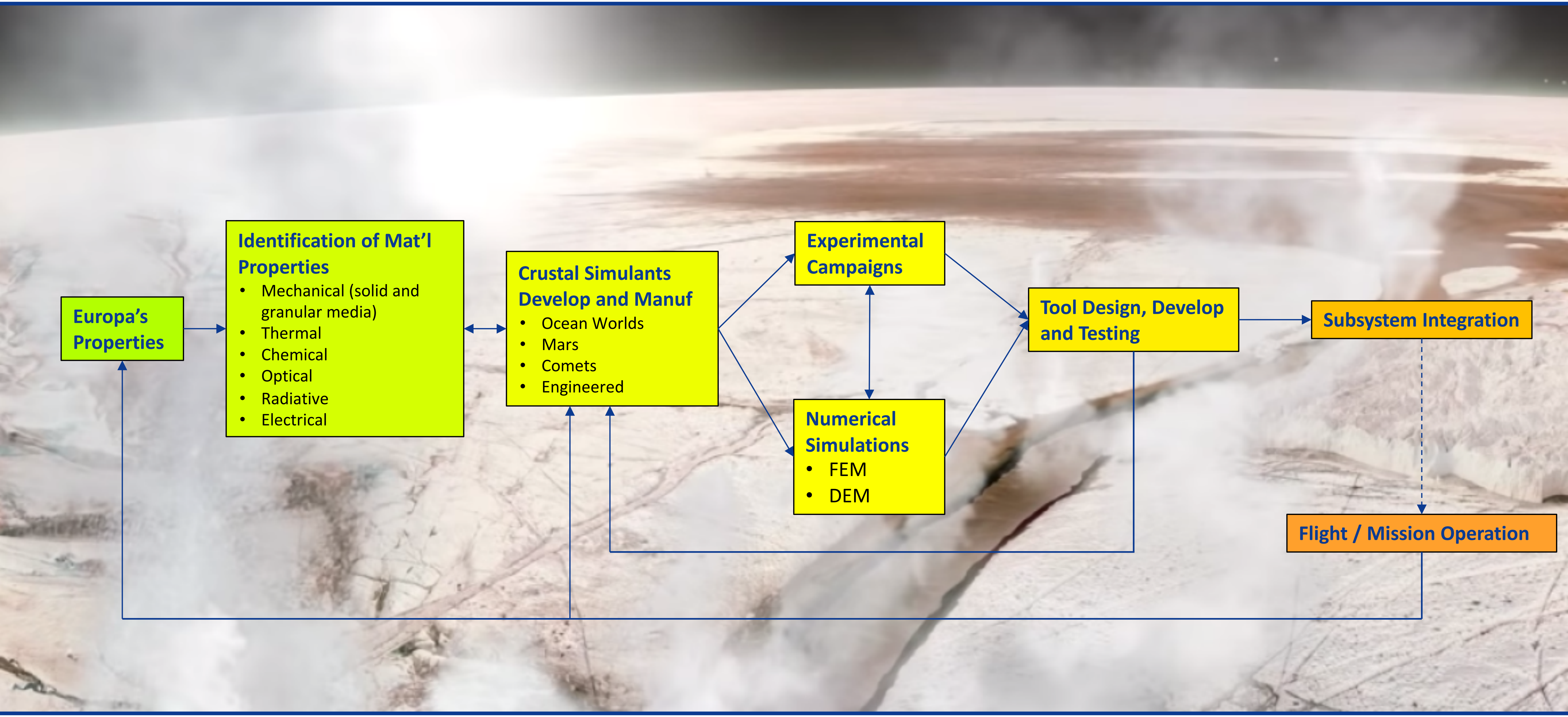
- Populate **Database** of simulant material properties
- Unveil empirical **correlations** with tool performances
- Build **models** to help us faster develop tools (for Europa Lander and for future missions)



Possible: broad physical space due to lack of knowledge
Reasonable: the more we know, the more targeted the design (smaller space)
Robust: expansion of the reasonable space based on tool capabilities and prediction of failures

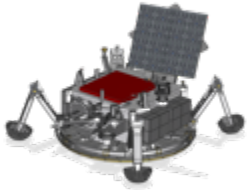
Flow Chart of Development Plan

for Europa Lander mission concept



Mean-Failure Energy

Dynamic Regime

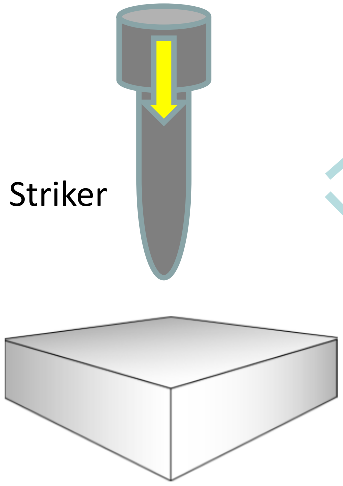


High Energy System

Drop Tower

Environmental Chamber

Striker



Material Failure

Decrease drop height and repeat

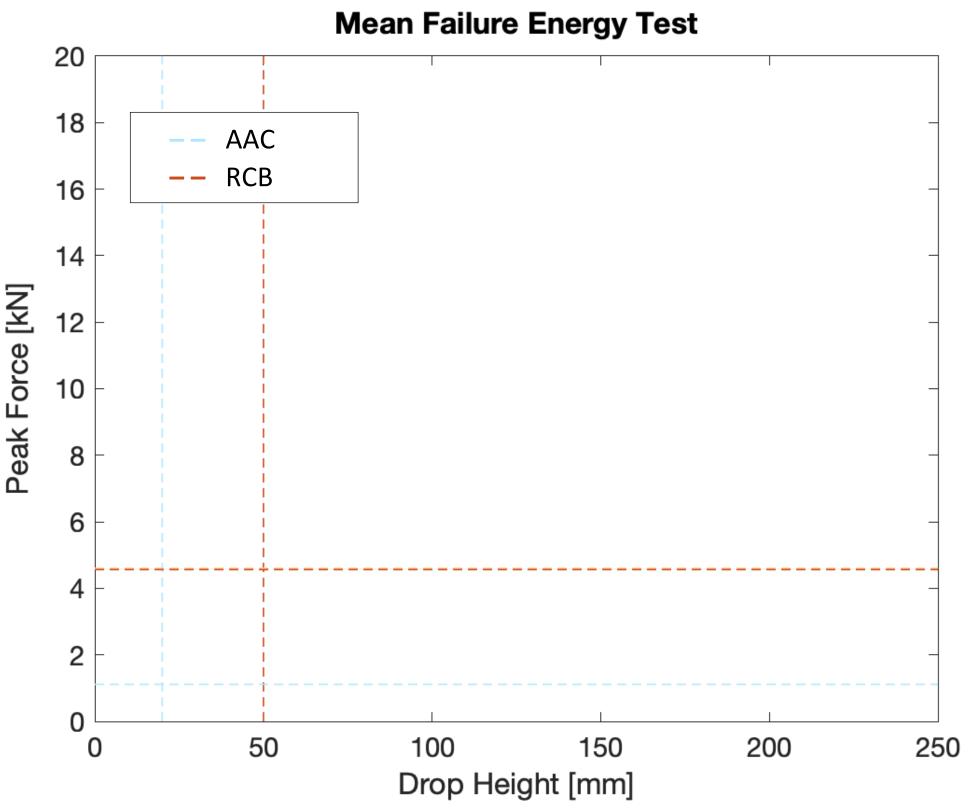
Material Intact

Increase drop height and repeat

MFE = $h\ w\ f$

Mean-Failure Energy

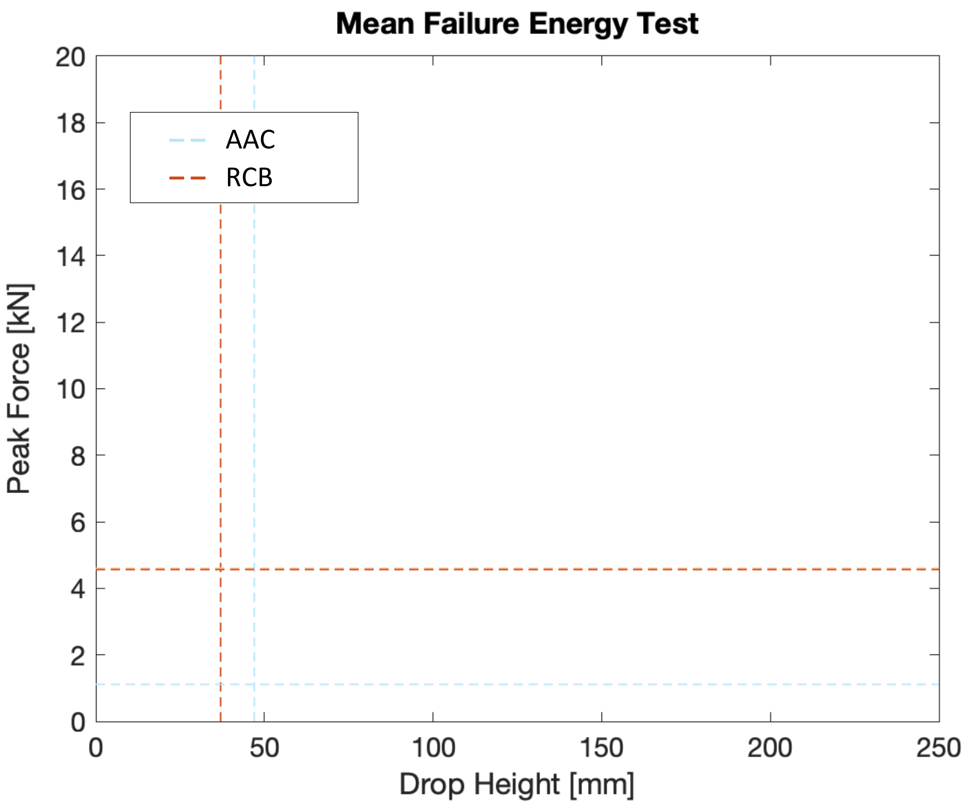
Expected



- We started purchasing equipment, **tune up** machineries and build up knowledge
- We started shaking out our procedures using two materials:
  - Autoclaved aerated concrete (**AAC**)
  - Red clay brick (**RCB**)
- In the plot is the behavior we expected for **mean-failure height** (vertical dashed lines):
  - RCB's peak force **higher** than that of AAC
  - RCB's mean-failure height/energy **higher** than that of AAC

Mean-Failure Energy

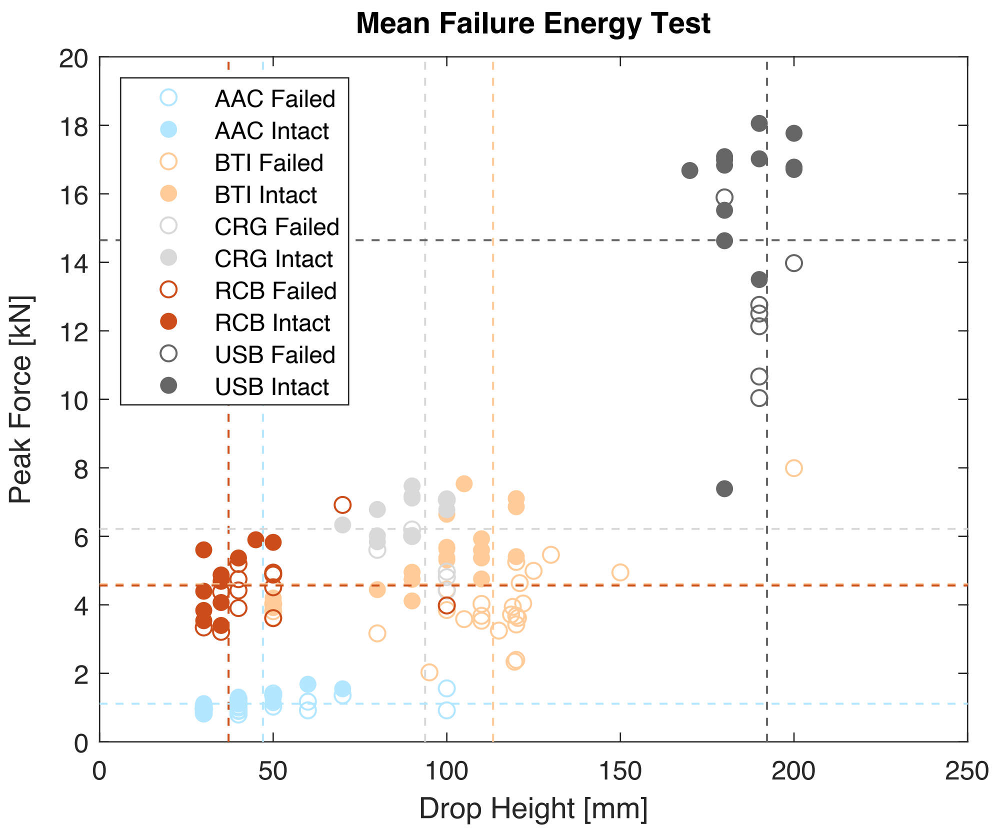
Actual



- In the plot is the behavior we expected for **mean-failure height** (vertical dashed lines):
  - RCB's peak force **higher** than that of AAC
  - RCB's mean-failure height/energy **lower** than that of AAC
- This has implication in the way a **tool** interacting with AAC vs. RCB has to be **designed**.

Mean-Failure Energy

Rocks – Mars surface simulants



List of materials tested via MFE

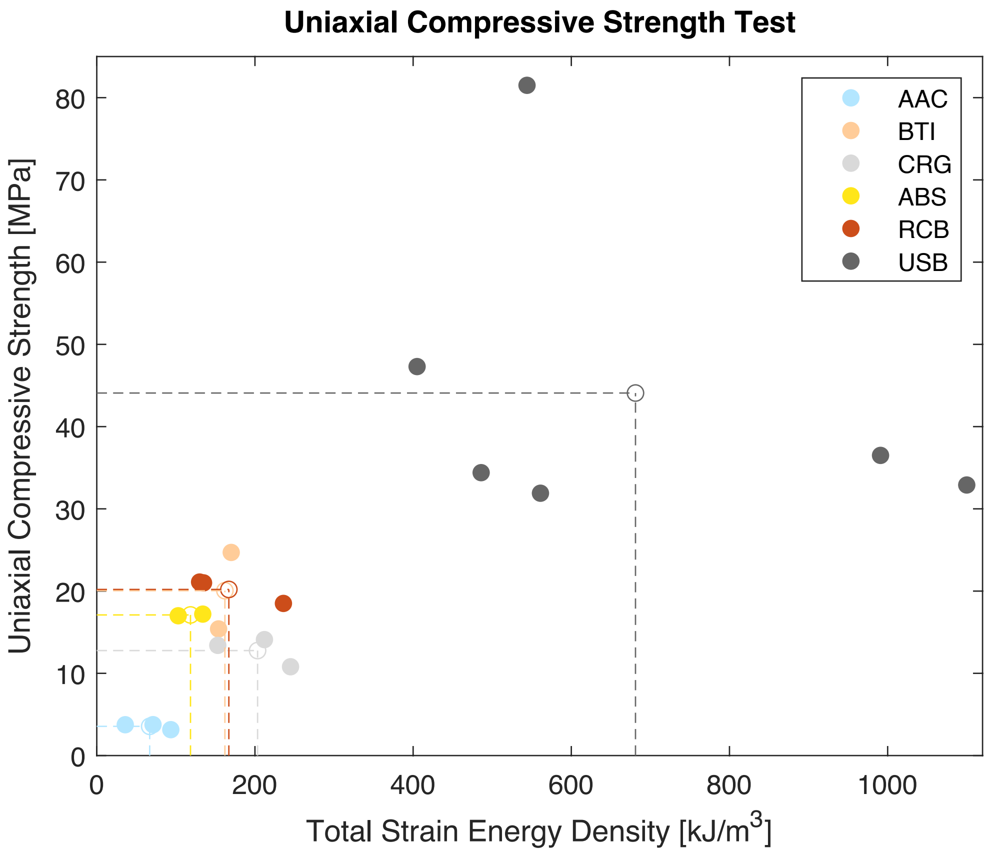
Material	Peak Force [kN]	Mean-Failure Height [mm]	Mean-Failure Energy [J]
AAC Failed	1.09	47.05	2.43
AAC Intact	1.15		
BTI Failed	4.01	113.33	6.89
BTI Intact	5.45		
CRG Failed	5.58	93.75	4.84
CRG Intact	6.66		
RCB Failed	4.46	37.14	1.92
RCB Intact	4.68		
USB Failed	12.57	192.22	9.93
USB Intact	15.77		

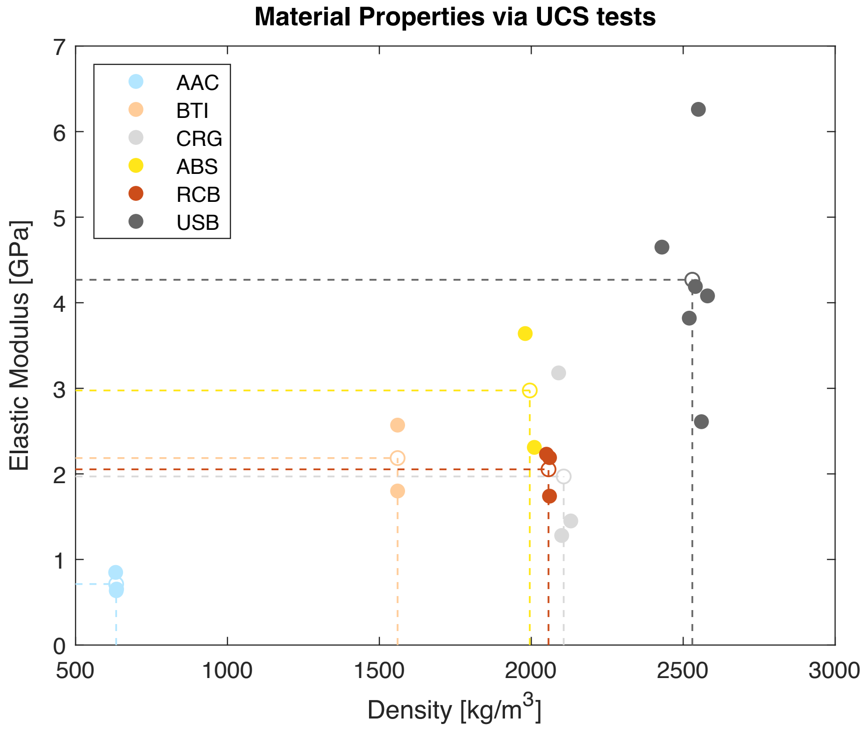
- The plot represents peak force vs. failure height from MFE tests.
- Empty symbols correspond to failed test articles, while full symbols correspond to intact ones.
- The dash lines refer to the average values of peak force and the calculated mean-failure (drop) height, respectively.
- The color code is representative of the materials under investigation.

Uniaxial Compressive Strength

Rocks – Mars surface simulants

UCS, Total strain energy density, Elastic Modulus

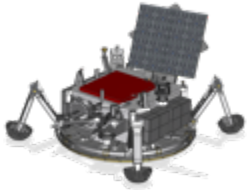




Average Materials Properties via UCS tests*

Material	Elastic Modulus [GPa]	Uniaxial Compres. Strength [MPa]	Strain Energy Density [kJ/m^3]
AAC	0.7	3.6	66.9
BTI	2.1	20.1	162.0
CRG	2.0	12.8	203.3
ABS	3.0	17.1	118.5
RCB	2.1	20.2	167.0
USB	4.3	44.1	681.2

Future Work – JPL



Techniques:

- Digital Image Correlation (DIC)
- Ultrasonic Tester
- Charpy / Fracture Toughness

Simulants:

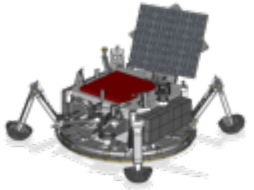
- Ice manufacturing
- Granular

Other properties we need help with:

- Optical
- Thermal
- Electrical

Ultrasonic Tester

Pressure and shear piezo-electric transducers

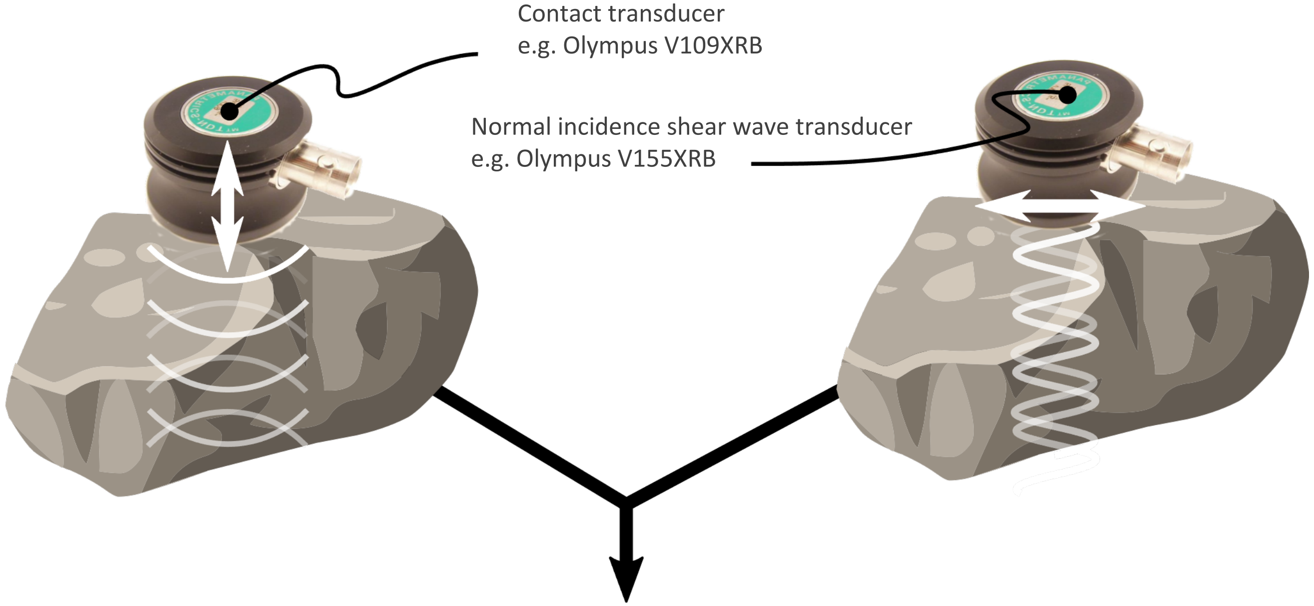


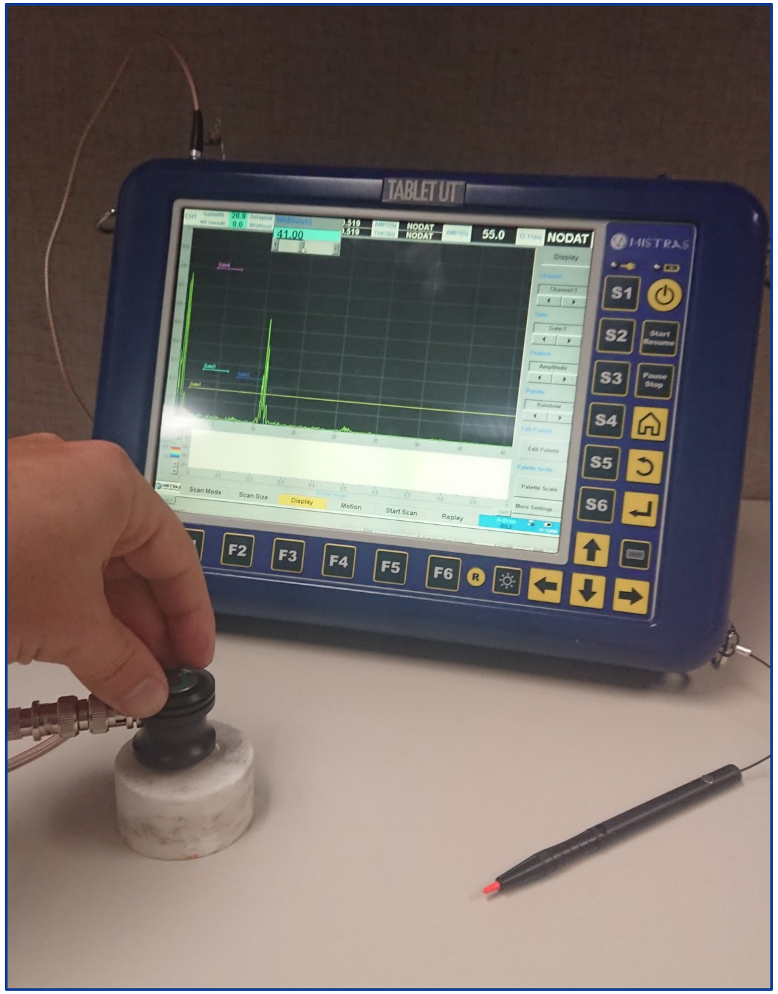
Measure pressure wave speed

- Piezo crystal pulses in direction of wave propagation
- Use couplant to reduce impedance contrast, especially on non flat surfaces

Measure shear wave speed

- Piezo crystal pulses perpendicular to wave propagation
- Travel speed is roughly half as fast as P waves
- No transmission through liquid; viscous couplant required





Calculate elastic properties

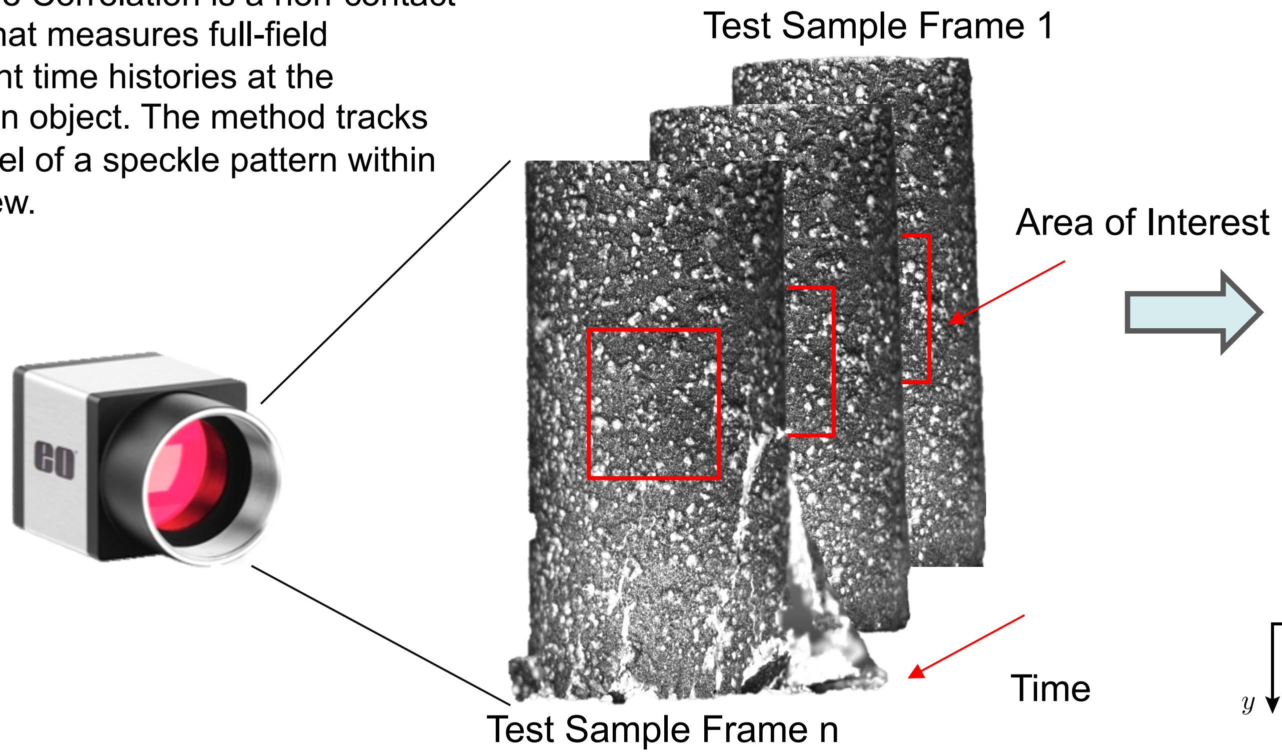
- Young's modulus
- Poisson's ratio
- Shear modulus

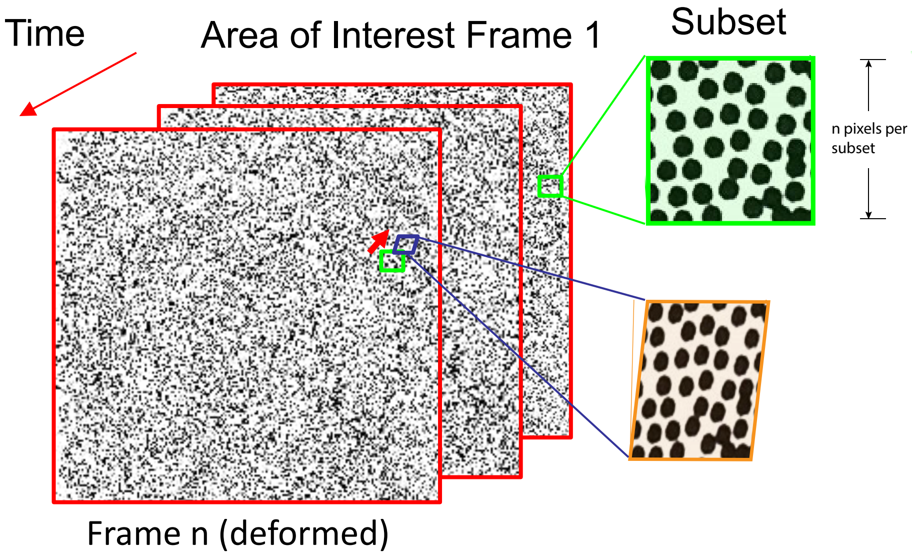
A. Curtis

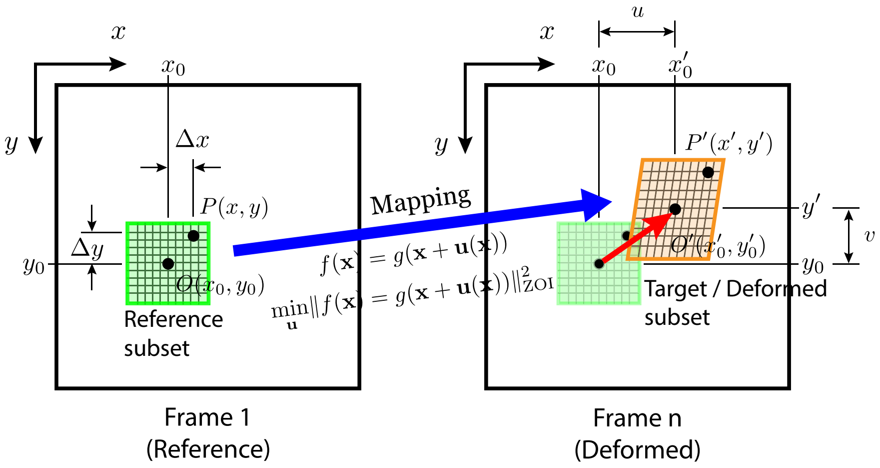
Digital Image Correlation

Direct measurement of 2-D displacement fields

Digital Image Correlation is a non-contact technique that measures full-field displacement time histories at the surface of an object. The method tracks the gray level of a speckle pattern within a field of view.



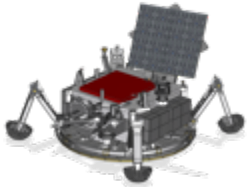


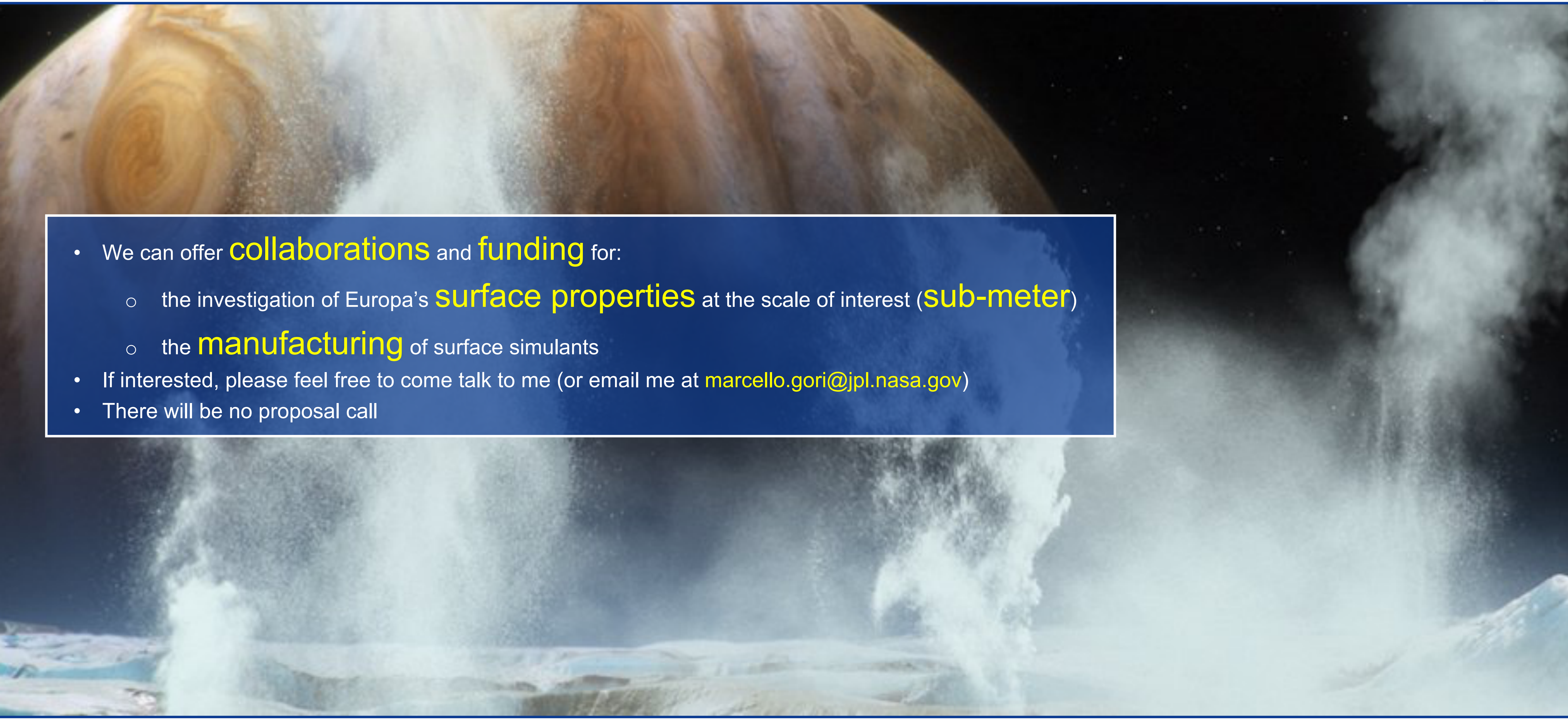


Full-field strain maps along the loading axis (vertical) can be obtained by the spatial gradients of the displacement fields. The fields can be averaged in order to give a single value to be correlated with the average vertical stress measured by the load cell.

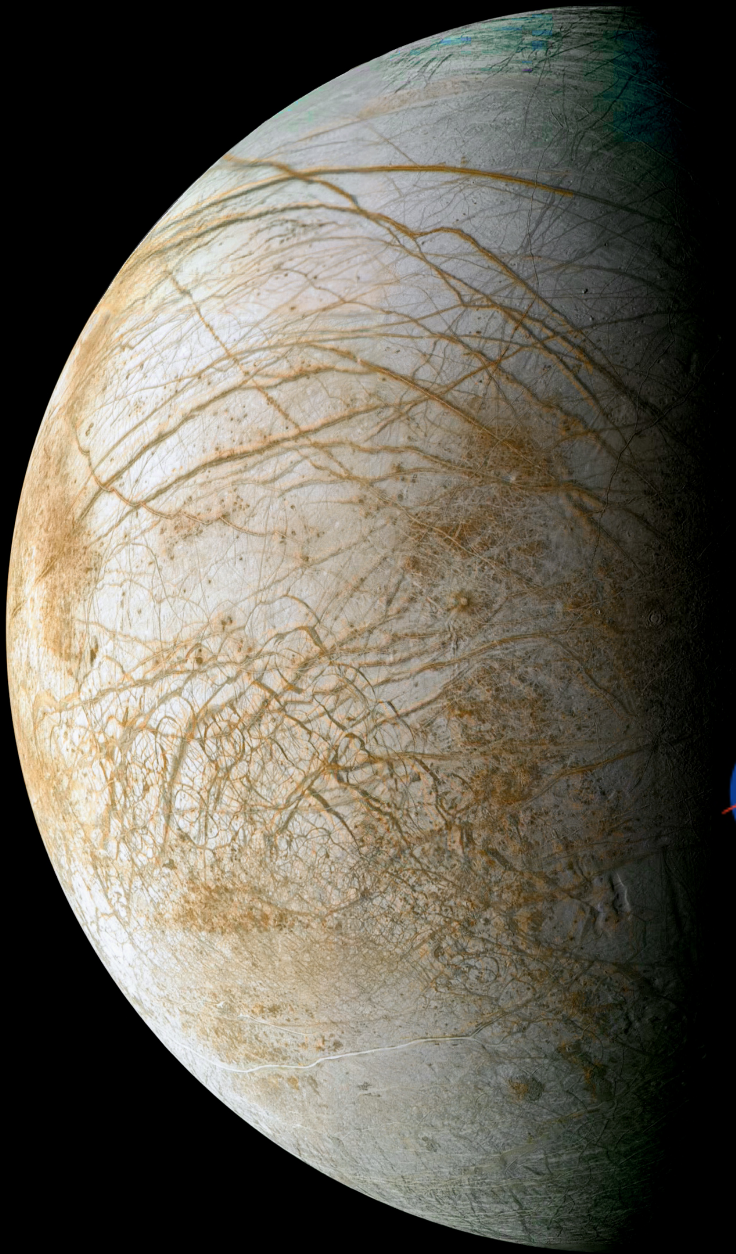
$$\bar{\varepsilon}_{yy} = \frac{\Delta y}{y_0}$$

Collaborations with JPL





- We can offer **collaborations** and **funding** for:
  - the investigation of Europa's **surface properties** at the scale of interest (**sub-meter**)
  - the **manufacturing** of surface simulants
- If interested, please feel free to come talk to me (or email me at marcello.gori@jpl.nasa.gov)
- There will be no proposal call



Thank you

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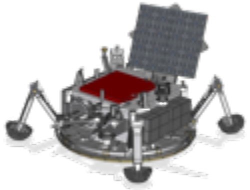
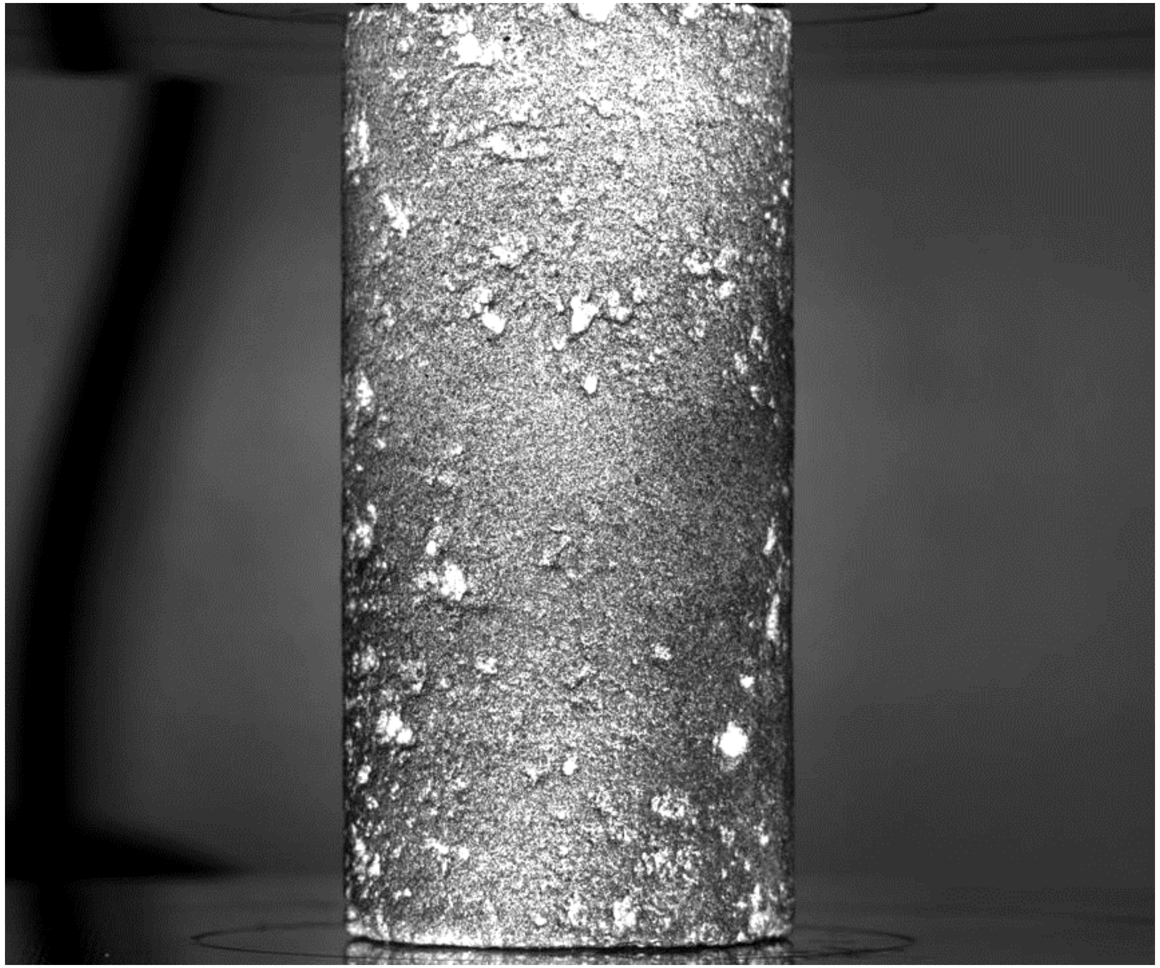


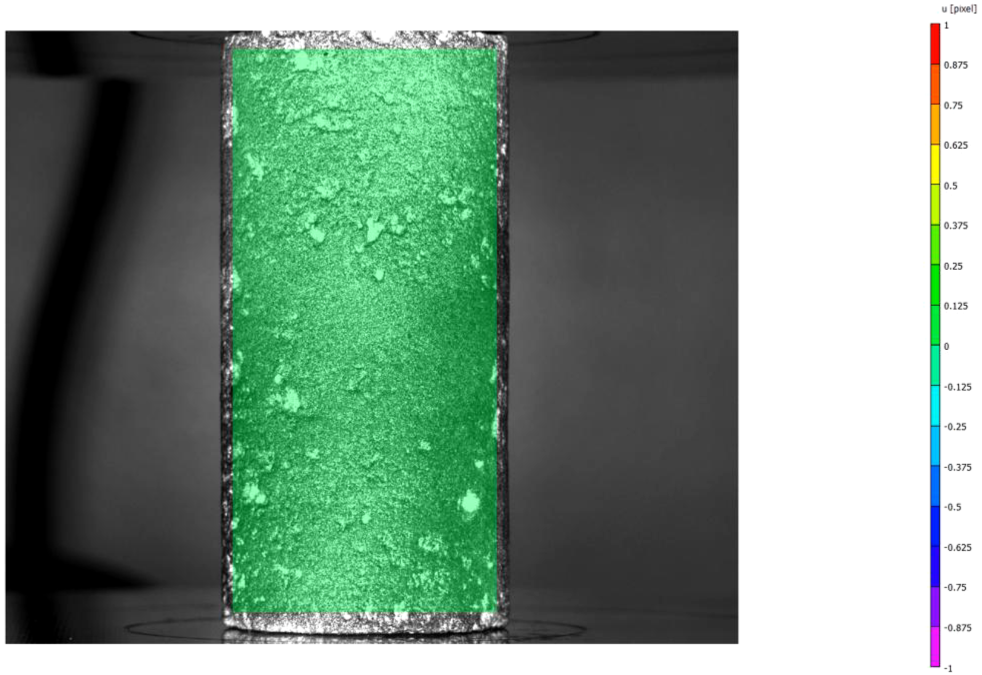
Backup slides

Digital Image Correlation

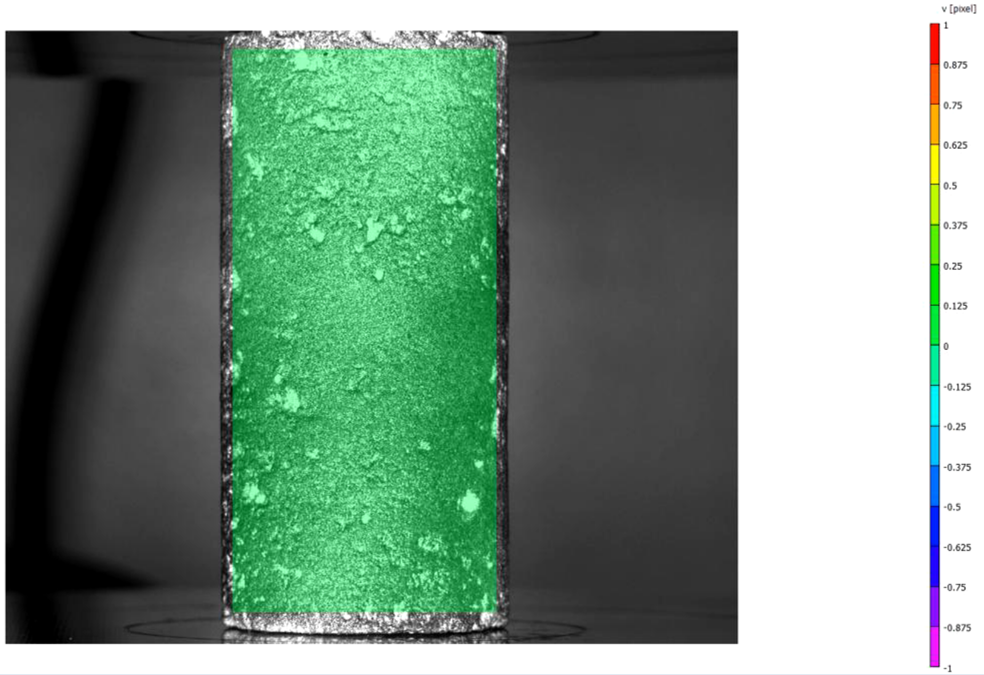
Quasi-static compressive load



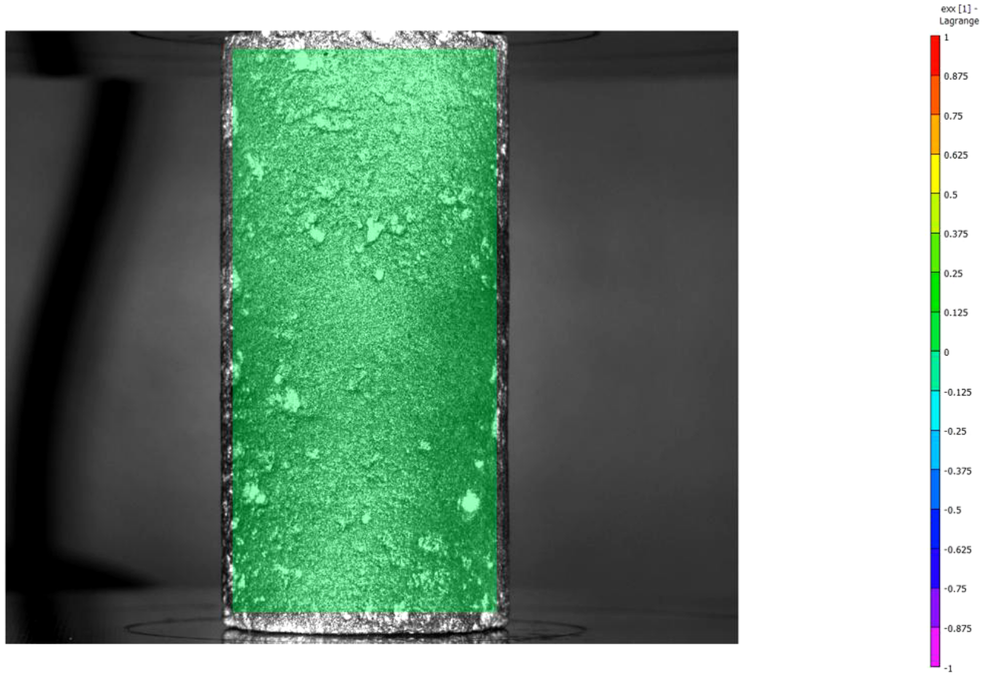
Horizontal displacement



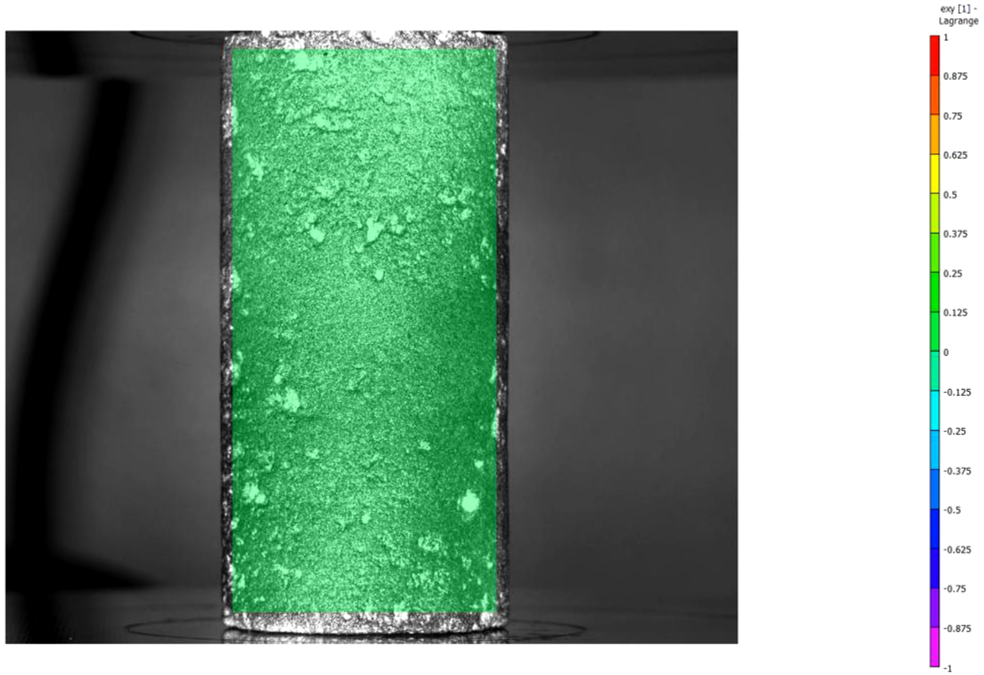
Vertical displacement

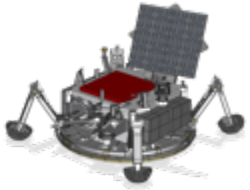


Horizontal strain



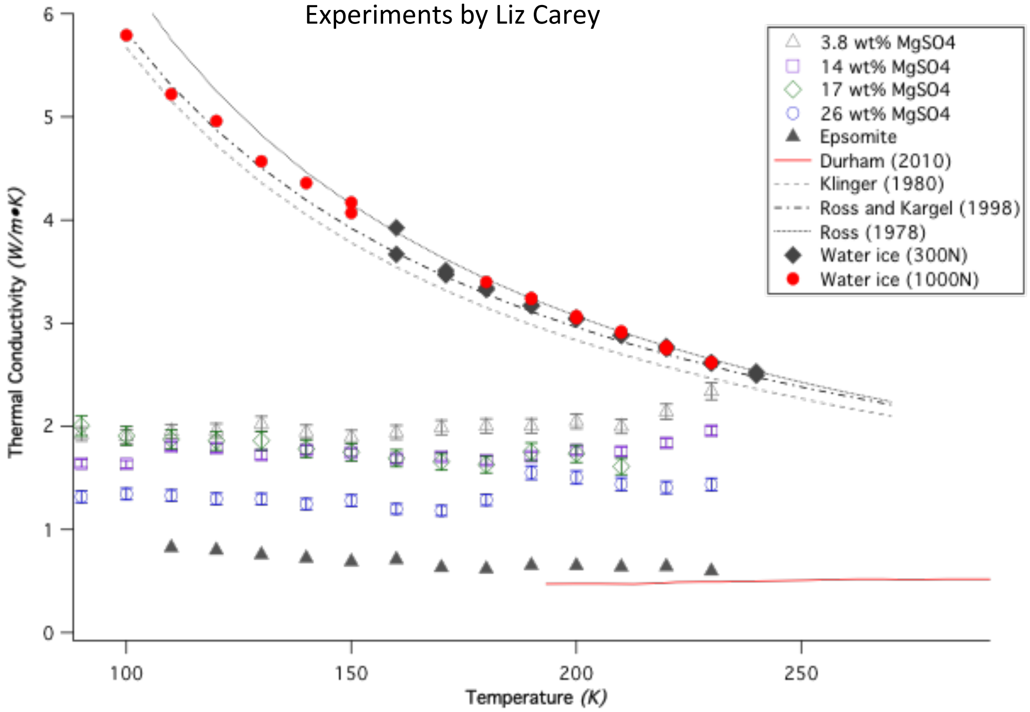
Shear strain



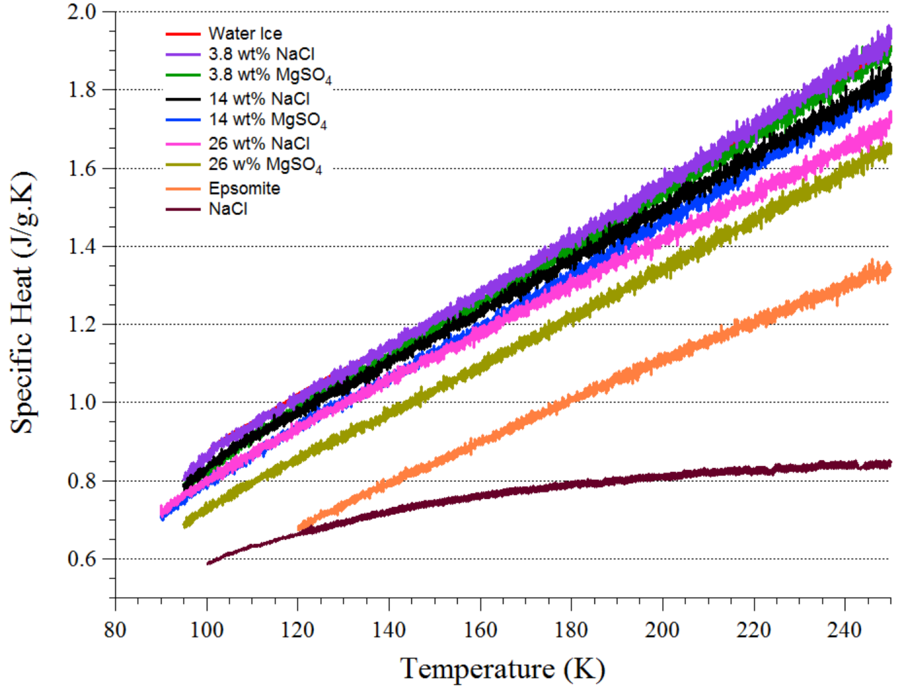


Thermal Properties of 'Salty' Ice

Dependence on temperature and chemical composition



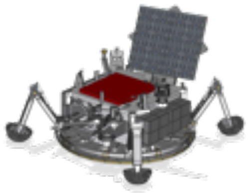
Experiments by Tuan Vu and Mathieu Choukroun



Lower thermal conductivity means that it will take longer for the material to carry heat away from a hotter location (i.e., frictional interface between tool and ice) → **bad news** for sample thermal preservation < 120 K

Lower specific heat means that it requires less heat energy to increase the temperature of the material → **bad news** for sample thermal preservation < 120 K

Problem Statement



Europa's properties needed to design a mission

- Europa represents an exciting destination for a mission, due to its **potential** to harbour life.
- A mission to Europa encompasses **new challenges**.
- We have **little experience** sampling in an Europa-like environment
- The scientific knowledge of Europa is still in its infancy.
- In order to enable a mission to Europa, we need to **expand/deepen our knowledge**.
- We would like to solicit **additional research** and are open to **collaborations**.
- At this stage, a collaboration would primarily involve **Europa**; however, in the longer term, it may extend to **other Ocean Worlds** such as Enceladus, and other bodies such as Ceres, comets and asteroids.

Although the Europa Clipper Mission will enlighten us on many of Europa's uncertainties these answers may arrive too late in time to shape the design of the Lander based on them.